

RESTORATION OF THE ELWHA RIVER ECOSYSTEM AND ANADROMOUS FISHERIES

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ABSTRACT

Historically, the Elwha River in western Washington was renowned for an abundance and diversity of anadromous salmonids. Most of the river lies within Olympic National Park and remains in pristine condition, but two dams in the lower river have blocked all anadromous fish for more than 80 years. To restore the Elwha's historic fishery resources and resolve an impasse about federal licensing of the dams, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act in 1992. The act required an analysis of alternatives (dam retention with fish passage facilities versus dam removal) to achieve full ecosystem and fishery restoration. Analysis indicates that removal of both dams is the only alternative that will achieve full restoration, but dam removal and fish restoration efforts could span 20 years and cost from \$154 million to \$210 million. Although fish restoration poses problems because of limited native runs, sediment management presents the most significant environmental challenge and cost. An Environmental Impact Statement is now in preparation and baseline studies are underway to examine and describe changes to wildlife communities, water quality and chemistry, vegetation, aquatic insects, and resident fish populations. The Elwha River restoration project provides an excellent opportunity to examine the role and contribution of anadromous salmonids to ecological processes in Pacific Northwest ecosystems.

INTRODUCTION

In 1992, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495), the express purpose of which was the "full restoration" of the ecosystem and anadromous fish runs that historically inhabited the Elwha River in northwestern Washington state. The act is a unique opportunity for ecosystem and fishery restoration because it allows for removal of two hydroelectric dams on the Elwha River to accomplish this objective.

The unusual nature of this action resulted from several factors. The Elwha River largely lies within Olympic National Park, a United Nations-designated World Heritage Site and Biosphere Reserve. The river historically supported a rich and diverse anadromous salmonid fauna, but now more than 115 river kilometers (rkm) of pristine habitat are totally blocked by the dams. During the 1980s, licensing by the Federal Energy Regulatory Commission (FERC) became extremely contentious, due primarily to: national policy implications of licensing a project within a national park, the inability to design fish and wildlife mitigation measures capable of meeting federal, state, and tribal resource goals, and legal challenges by conservation groups for full fish and wildlife mitigation.

Removal of both dams emerged as an alternative to meet the goals of ecosystem and fisheries restoration. However, it appeared likely that any decision FERC might render, dam removal or licensure, would be challenged in court by one party or another. The U.S. Department of Justice, at the request of the U.S. Departments of Commerce and Interior, appealed a determination by FERC that it had authority to relicense Glines Canyon Dam within the confines of Olympic National Park. Prior to passage of the act, the North Pacific International Chapter of the American Fisheries Society passed a unanimous resolution calling for removal of the Elwha dams, while the Northwest Public Power Association passed a unanimous resolution to retain the dams.

Since costly legal challenges could delay the federal licensing or removal by perhaps a decade, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act in 1992. The act authorized the Secretary of the Interior to acquire and remove the dams if that action was the only means to fully restore the Elwha River ecosystem and native anadromous fisheries. If the Secretary determined that dam removal was necessary for full restoration, acquisition of the projects was authorized (for \$29.5 million), and the mill's electrical power was assured through the Bonneville Power Administration (BPA).

Here we contrast the past and present status of the Elwha River's ecosystem and anadromous salmonids, the restoration alternatives which were assessed in reaching the dam removal option, and update an earlier account of the proposed restoration process that would occur through dam removal (Wunderlich et al. 1994).

The Elwha River Ecosystem and Anadromous Salmonids

Basin Description

The Elwha River is located in the heart of the Olympic National Park. It flows north 71 km through old-growth forests before entering the Strait of Juan de Fuca near Port Angeles (Figure 1). Except for the two Elwha dams and the absence of anadromous fish, much of the Elwha River basin is pristine, unlike many other north Olympic Peninsula rivers which have been impacted by extensive land use, particularly timber harvest. Only limited development has occurred in the lower river.

Dam-related impacts are much more severe. Elwha Dam has stopped downstream movement of gravel for over 80 years, leaving the substrate in the lower 8 rkm in a very coarse condition; only limited amounts of substrate below both dams remain suitable for fish spawning. Lack of gravel recruitment has also significantly decreased the river's estuary.

The dams also raise water temperatures in the middle and lower reaches of the river in late summer and early fall due to storage of heat in their reservoirs. During years of low snow pack and rainfall, summer water temperatures exceed 18° C which result in large losses of pre-spawning adult chinook salmon in the lower river due to disease; about two-thirds of the 1992

return died prior to spawning. Mitigation involving flow augmentation has not succeeded in resolving this problem.

Fish and Fisheries

Prior to hydropower development, the Elwha River was considered the most prolific fish producing river on the Olympic Peninsula of Washington state. Early residents reported that migratory fish had unlimited access to the entire river and large runs of anadromous salmonids flourished (Schoeneman and Junge 1954). The Elwha was one of the few rivers in the contiguous United States which supported all the anadromous salmonids native to the Pacific Northwest: spring and summer-fall run chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*) and sockeye salmon (*O. nerka*), summer and winter run steelhead (*O. mykiss*), searun cutthroat trout (*O. clarki*), and searun native char (Dolly Varden (*Salvelinus malma*) and bull trout (*S. confluentus*)).

The Elwha River was particularly renowned for its run of large chinook salmon. Brown (1982) stated that these salmon were "easily the largest on the Olympic Peninsula." He recounts how Spanish explorers purchased a number of salmon of 45 kg (100 lbs) from Indians near the Elwha on July 25, 1790. These chinook salmon were apparently uniquely adapted to the temperature regimen, flow patterns, and other environmental variables found within the Elwha drainage, its estuary, and ocean migration route; some unknown factor or combination of factors selected for large size (Brannon and Hershberger 1984).

Before Olympic National Park was established, the Elwha River was dammed for hydropower generation (Figure 1). Elwha Dam was completed in 1912 at rkm 8 and consists of a concrete-and-earth structure that is 32 m high and 137 m long at its crest, creating a 4-km reservoir. Glines Canyon Dam began operating in 1927 at rkm 22 and consists of a concrete-arch structure 64 m high, impounding a 4.5-km reservoir. Power from both projects (average annual generation of 18.7 megawatts) meets about 38% of the electrical need of a nearby paper mill.

Neither Elwha nor Glines Canyon Dams has provision for fish passage. When Elwha Dam was constructed, Washington law required fish passage wherever food fish (salmon) migrated upstream. Nevertheless, only a mitigation hatchery was constructed, which collected more than 23 million eggs from Elwha River salmon and steelhead before ceasing operation in 1922 because "very few salmon ascended as far up the river as the dam" (Maib undated). Because Elwha Dam had no fish passage facilities, no provision for fish passage was considered necessary at Glines Canyon Dam.

Anadromous fish have been restricted to the 8 rkm below Elwha Dam for close to 80 years, and their numbers are acutely reduced due to loss of upriver habitat. Nehlsen et al. (1991) list native Elwha River sockeye salmon as extinct, spring chinook and chum salmon as possibly extinct, pink salmon at high risk of extinction, and searun cutthroat to be of special concern. Summer steelhead are considered depressed (WDF et al. 1993).

Unfortunately, no large-sized (45 kg) chinook salmon have been observed in the Elwha River for many years. The size of Elwha chinook salmon now appears to be typical of most other Puget Sound and Washington coastal rivers. However, Brannon and Hershberger (1984) believe the genetic potential for large fish has been preserved in the remnant stock, but current hatchery practices are suppressing its expression.

While anadromous fish in the Elwha River suffer from many of the problems common to other Washington salmon, dam-related impacts remain the most serious threats. Overharvest

in mixed ocean fisheries remains a significant concern for Elwha chinook and coho salmon, although harvest restrictions being considered for weak stocks of Washington and Oregon salmon should benefit Elwha stocks.

Recreational and treaty Indian fishing occurs in the river for hatchery produced coho salmon and steelhead. Harvest of other species has been curtailed to protect remnant stocks, including chinook salmon. The Lower Elwha S'Klallam Tribe, which has treaty rights to these fish, has shared in the burden of protecting these fish over the years and is a strong advocate of the restoration effort.

Current Hatchery Production

Hatcheries have been constructed in the lower river by the Lower Elwha S'Klallam Tribe and the Washington Department of Fish and Wildlife (WDFW). The tribal facility produces coho salmon and winter-run steelhead, but harvest of these fish fluctuates widely and has been relatively low. The state facility releases chinook salmon that are caught in substantial numbers in marine fisheries, but there is no in-river recreational fishing and only very limited tribal fishing for this species. The state facility continues to encounter problems in acquiring adequate eggs to meet its needs; disease and parasites have taken a heavy toll on the adults prior to spawning.

Alternatives for Ecosystem Restoration

Assessment Approach

In assessing fish passage, it was assumed that measures to restore anadromous fish would include upstream and downstream passage facilities and operation of Glines Canyon Dam in a run-of-the-river mode with continuous spill for passing downstream migrants (USDI et al. 1994). To pass fish at Elwha Dam, an adult fish ladder, juvenile fish screen system, and spillway improvements would be installed. To pass fish at Glines Canyon Dam, a trap-and-haul operation would be necessary for adult fish, as well as continuous spill and a facility for screening juvenile fish away from the turbine intake.

Alternately, removal of both dams would involve elimination of both structures and management of accumulated reservoir sediments. Dam removal would result in unobstructed juvenile and adult fish passage, restoration of inundated habitat, and recovery of natural physical processes (i.e., sediment and nutrient transport, hydrology, and temperature regimens) in the lower river.

The prospect for restoring each fish stock was qualitatively assessed under the alternatives of dam retention (with state-of-the-art fish passage) or dam removal (either or both dams). Site-specific information on expected fish passage success at each dam and reservoir (Hosey and Associates 1988; Wunderlich and Dilley 1990) and expected recovery of habitat within the historic range of each stock (Figure 1) were evaluated. Availability of brood sources was also considered as six of the ten native Elwha anadromous fish stocks are either extinct or acutely reduced, and replacement stock is limited within the region (WDF et al. 1993). Harvest impacts were also evaluated.

The prospect for recovery of the river's native biological populations and its natural physical processes (collectively considered "ecosystem restoration" here) was qualitatively assessed for each alternative. As an indicator of ecosystem recovery, the magnitude and timing of potential salmon biomass (carcass) contributions in the Elwha River basin were compared

for each alternative (USDI et al. 1994). This comparison assumed full use of available habitat (i.e., spawner escapement based on optimal seeding for stocks with at least a fair prospect for restoration under each alternative), and reflected differences in recovered habitat rather than differences in recovered run sizes. Additional salmon biomass contributions (i.e., potential egg and juvenile mortalities) would also occur, but they would not approach the contribution of adult carcasses.

Salmon biomass contribution and ecosystem response were assumed to be directly related. A principal benefit of fish in the ecosystem is their contribution to the prey base. Cederholm et al. (1989) found that at least 22 species of birds and mammals use salmon carcasses as a seasonal food source in Olympic Peninsula streams. Spencer et al. (1991) found that the collapse of kokanee (*O. nerka*) in Flathead Lake, Montana, was accompanied by great reductions in wildlife which fed upon the kokanee, their carcasses, and eggs. Hansen (1987) noted that breeding adult eagles fed almost exclusively on salmon carcasses, eulachon (*Thaleichthys pacificus*), and Dolly Varden in southeast Alaska streams. When salmon carcasses were abundant, greater nesting activity, more active nests, earlier laying dates, higher juvenile survival, and greater fledgling rates occurred than in years of low returns. Stalmaster and Gessaman (1984) found similar results in Puget Sound.

Juvenile fish are also important wildlife prey. Of 286 species of birds occurring in Olympic National Park, one-third consume fish as a primary or incidental source of prey. Heggens and Borgstrom (1988) found relatively high predation rates by mink on juvenile Atlantic salmon and brown trout (*S. trutta*).

Fish carcasses and unhatched eggs also contribute nutrients derived from the ocean to the freshwater ecosystem. Increased nutrients have been observed in streams in Alaska (Brickell and Goering 1970) and Washington (R. Bilby and P. Bisson, Weyerhaeuser Company, personal communication) due to salmon carcass decomposition. Walter (1982) estimated that a run of 50,000 pink salmon added 3 metric tons of nitrogen and 0.3 metric tons of phosphorus to a small Alaskan stream.

One mechanism by which fish carcasses stimulate biological productivity appears to be their influence on detrital activity. Durbin et al. (1979) found that spawning alewives (*Alosa pseudoharengus*) stimulated the detrital food chain due to inputs of nitrogen and phosphorus.

In the Elwha River, resumption of these natural processes is a principal goal which can only be achieved if all species are restored. Historically, fish returned throughout the year and utilized all accessible reaches. Differences in spawning and rearing sites resulted in wide distribution of prey and nutrient benefits over a significant portion of the year. For instance, coho, bull trout/Dolly Varden, summer steelhead and searun cutthroat would be expected to penetrate high into tributaries, spreading prey and nutrients to terrestrial species which do not migrate over long distances. On the other hand, chum salmon would provide a substantial pulse of carcasses in early winter when other sources of prey are not readily available to predators and scavengers.

Consequences of Alternatives

Comparing the alternatives of fish passage and dam removal indicates that retention of either or both dams, even with the provision of fish passage facilities, would not allow for the full restoration of native anadromous fisheries such as chinook, chum, and pink salmon, among others (USDI et al. 1994). Assessments by the U.S. General Accounting Office (1991) and FERC (1993) have closely agreed.

Cumulative losses of juveniles and adults in the reservoirs, spillways, turbines, passage facilities, and degraded habitat greatly reduce the chances of restoring viable populations for all species except coho salmon and steelhead (Table 1). The reservoirs constitute virtually insurmountable barriers to outmigrating chum and pink salmon, the most abundant species historically, and inundate much of their historical spawning habitat (Figure 1). Chinook salmon would experience losses during upstream passage in ladders and trap-and-haul facilities, in addition to juvenile losses during downstream passage in reservoirs. Continued pre-spawning mortality of chinook would occur in the lower river in years of low summer streamflow.

With retention of either or both dams, ecosystem restoration would be significantly compromised as indicated by reduced inputs of biomass (Table 2), especially from fall to spring when large inputs of chum and pink salmon biomass would otherwise be available. Moreover, retention of either or both dams would prevent downstream nutrient and organic transport, as reservoirs are known to block movement of these materials (Webster et al. 1979; Newbold 1987). Important riverine habitat would remain flooded by the reservoirs. Historically, these reaches were mostly broad alluvial valleys of moderate gradient (averaging less than 1%) that were used by all anadromous fish species for spawning, rearing, and migration. Trapping of bedload with the consequent loss of spawning substrate below the dams would also continue.

In contrast, dam removal and restoration of anadromous fish would result in returns of fish to the river throughout the year, optimize use of all accessible portions of the watershed, produce much greater numbers of fish, and restore ecosystem processes. Wildlife prey would be provided by fish carcasses, juveniles, and eggs. Removal of the two reservoirs would allow nutrients and bedload (sand, gravel, and cobble) to naturally pass downstream.

With dam removal, the river's historic fisheries, except possibly for sockeye salmon, could resume (Table 1). Most of the river's stocks would take advantage of the large amounts of pristine habitat within the park and could be expected to provide harvestable surpluses. Lower-river spawners, such as chum and pink salmon, could require a longer recovery period as the lower river stabilizes after dam removal. Anadromous fishing opportunities would expand from the 8 rkm currently available to the entire river. Catches would also shift away from fisheries of short duration targeted on hatchery stocks to year-round fisheries on wild stocks.

Proposed Restoration Process

Dam Removal and Sediment Management

The principal steps involved in removing the projects would include diverting the river around the dams in tunnels or channels, through newly constructed low-level outlets, or over the dams by creating notches through the structures and progressively lowering the reservoirs as layers of the dams are removed. The notch approach appears to be the most feasible and economical at this time.

For nearly 80 years the projects have acted as large settling basins, slowing the velocity of the river and trapping sediments. About 1 million m³ of sediment have accumulated in Lake Aldwell and nearly 9 million m³ in Lake Mills, most of which is deposited in deltas at the head of each reservoir. Options for managing the accumulated sediments include mechanical removal to a saltwater or terrestrial site, stabilization in place, natural river erosion downstream, and a combination of these. Whereas uncontrolled release of sediments could cause severe short-term impacts, sediment is also a resource that is needed in the middle and

lower river to improve spawning and rearing habitat. Options that allow natural erosion of the coarse materials (e.g., sands, gravels, and cobbles) downstream hold promise for the quickest recovery of instream habitat, as well as lower costs. Fines (e.g., silts and clays) could be naturally eroded, for the most part, over one to two years resulting in high levels of in-river suspended sediments or they could be slurried to saltwater, thereby minimizing in-river impacts. High water velocities in the Strait of Juan de Fuca would disperse sediments and minimize impacts to the nearshore environment. In all instances, natural recovery of sediments in the river and nearshore environment offer substantial long-term benefits to fishery resources.

The ultimate choice of a sediment management strategy rests on short-term impacts to existing fisheries and water users, the need to restore the original stream channel and floodplain habitat currently inundated by the reservoirs, and costs. Mechanical removal of all sediments would deprive the river and estuary of needed coarse sediments and would be the most costly option. Stabilization of all sediments would prevent full restoration of the inundated areas. Natural erosion of the accumulated sediments could have significant short-term impacts from extremely high suspended sediment levels, but it would also allow for the quickest recovery of coarse material to the river and estuary. It is likely that a combination of these options (e.g., slurry fine material to saltwater and erode coarse material downstream) is the most feasible.

Ecosystem and Fishery Restoration

The cornerstone of ecosystem and fishery restoration for the Elwha River is the expected recovery of native anadromous fish runs following dam removal and restoration of inundated terrestrial and riverine habitat. Natural recovery of wildlife populations is expected to occur following habitat recovery and restoration of all anadromous fish runs. However, we acknowledge that restoration is an ongoing process and not easily fixed to any specific time period.

Precise replication of past habitat conditions within the lake basins would be impossible, but written records, historic photographs, and rich oral history provide a guide for habitat restoration. Prior to inundation, these broad alluvial valleys were bordered by steep forested slopes. During dam removal, habitat restoration actions would consist of immediate, short-term measures to provide erosion control and form a suitable substrate for native species regeneration, which should occur relatively quickly.

We are unaware of other ecosystem restoration efforts on the scale of Elwha. Consequently, the Department of the Interior hopes to document the present conditions and track changes for 10 years after dam removal is completed. Towards that end, federal agencies and the Elwha S'Klallam Tribe are making "baseline" measures of water quality, in-river aquatic populations, distribution of large woody debris, wildlife use, sediment levels, and terrestrial habitat.

Anadromous fish restoration activities are necessarily intertwined with the expected timing of complete dam removal (no sooner than 1998) and re-establishment of a relatively stable river channel in the former dam-and-reservoir sites. Rebuilding Elwha River anadromous fisheries may span at least 20 years, and will likely include brood development and juvenile outplanting for at least some stocks, followed by evaluation of adult returns and ecosystem response (USDI et al. 1994). Management of impacting fisheries is an integral part of fisheries restoration and, over the rebuilding period, harvest rates would be phased down on stocks presently supported by hatchery production (chinook and coho salmon and steelhead) to a level conducive with wild production.

A key assumption in rebuilding the Elwha fish runs is that juvenile outplanting would significantly speed fish restoration and, as noted below, allow reintroduction of fish stocks better adapted to the Elwha River's unique environment than presently exist in the lower river. Planning for hatchery involvement will recognize the uncertainties associated with supplementation intended to rebuild self-sustaining natural stocks. Reviews of this subject (Wunderlich and Pantaleo 1994; Federenko and Shepherd 1986) indicate that relatively few truly successful examples exist. Artificial rearing pre-disposes hatchery fish to higher risks of predation, lower feeding efficiency, and suboptimal habitat use compared to wild fish, and these maladaptive traits may be passed on to wild fish through interbreeding (BPA 1992). Primary considerations in hatchery rearing of outplants intended for Elwha River anadromous fish restoration will therefore be to:

- ▶ Limit hatchery exposure. First-generation hatchery impacts occur which can adversely affect long-term survival in the wild, so pre-smolt outplanting will receive emphasis. Pre-smolt outplants may exhibit better survival in the wild than smolt releases owing to increased natural selection in the stream environment (R. Reisenbichler, National Biological Survey, personal communication), and have generally had a better track record of supplementation in barren habitat than have smolt outplants (WDF 1992).
- ▶ Use innovative hatchery practices. Such practices mimic natural incubation and rearing (such as overhead cover and sub-surface feeding in raceways), and recent evidence suggests this hatchery environment improves foraging and predator-avoidance behaviors of hatchery fish in the wild and may confer a significant, long-term survival advantage (S. Schroeder, WDFW, personal communication).

Re-introduction of existing Elwha fish stocks should yield the greatest adult return (Nickelson et al. 1986; Reisenbichler 1988), and use of native Elwha stock is a first priority in rebuilding fish runs. However, past hatchery introductions and loss of upriver habitat due to the dams have depleted native Elwha stocks so non-native introductions may be necessary for some stocks.

Natural recolonization is fully anticipated where source stock exists because adult anadromous salmonids would gradually penetrate the upper drainage and re-establish themselves once access is regained. In Puget Sound, for example, when access to 145 rkm in the upper Skykomish River above Sunset Falls (a natural barrier) was provided, chinook and pink salmon penetrated the upper reaches of the basin, and their populations peaked in 15 and 25 years, respectively (Seiler 1991).

More than one restoration option is identified to restore most Elwha fish stocks; primary options and a timeline for re-introduction are shown in Table 3. Where outplanting is anticipated, two cycles of each major activity (identification and development of brood stock, as necessary, followed by outplanting and evaluation of adult return) are depicted to give perspective on the time scale involved. Restoration planning efforts would initially be directed toward all options, but those that demonstrate most promise would eventually be pursued.

Restoration of spring chinook salmon would primarily rely on outplanting juvenile summer/fall Elwha stock in their historic range (the uppermost reaches of the basin) and then allowing natural processes to establish an early run (Table 3). Chinook salmon are known to adapt rapidly to new situations (Healey 1991), and significant shifts in spawn timing have been reported in response to new environmental conditions (Kwain and Thomas 1984). In the Elwha, the existing summer-fall chinook salmon stock could eventually exhibit an earlier timed component (spring type), responding to the upper river's cooler temperature regimen, which requires an earlier return and spawn timing to complete the life cycle (E. Brannon, University

of Idaho, personal communication). Whether Elwha chinook would again exhibit their large size (up to 45 kg) is problematic; however the environmental conditions that produced these large fish would again be available.

Summer-fall chinook and coho salmon in lower river hatcheries would serve as a ready source of brood for outplanting. Coho salmon would initially be introduced above rkm 26, the assumed limit of chum and pink salmon (Figure 1), to reduce predation on these species. Juvenile coho salmon are important predators of juvenile chum and pink salmon, and separation of these stocks in space or time is an important management consideration in Puget Sound hatchery releases (J. Ames, WDFW, personal communication).

Chum and pink salmon restoration would entail rebuilding remnant Elwha populations or importing stocks from nearby sources, such as Strait of Juan de Fuca streams (chum salmon) or the Dungeness River and Hood Canal (pink salmon). Sockeye salmon restoration would involve either importing a suitable stock or allowing natural re-establishment of the anadromous component of Lake Sutherland kokanee, assuming it retains a significant genetic element of the original Elwha sockeye.

Restoration of Elwha steelhead would focus on use of native Elwha stock. Reisenbichler and Phelps (1989) suggest that the upper Elwha River rainbow trout (*O. mykiss*) may be descendants of the original Elwha steelhead, trapped in the upper river since Elwha Dam closed. Up to 1,000 steelhead smolts emigrated from the upper river in 1994 (Hiss and Wunderlich 1994), so a small, upriver native brood source may be available. Alternatively, remnant runs may still exist in the lower Elwha River which could be enhanced.

To rebuild native runs of searun cutthroat and native char, natural recolonization would be relied on. Remnant, landlocked forms of these species may also exist in the upper watershed in an analogous manner to rainbow/steelhead.

Restoration Costs

Total costs of project acquisition, fish and habitat restoration, water quality protection for downstream users, and dam removal and sediment management for the most realistic alternatives range from \$148 million to \$203 million over 20 years (USDI et al. 1994). Dam removal and sediment management are the single greatest costs and will most likely range from \$67 million to \$80 million for 3 to 8 years. If all accumulated sediments were completely removed, the total project cost could be \$307 million. Complete sediment removal is not recommended at this time, but would be explored during the EIS process, occurring now through the spring of 1996.

The estimated cost of dam retention with fish passage facilities has been estimated at \$46 million for 30 years (FERC 1993). However, this alternative fails to include turbine screens at Glines Canyon Dam and gravel replenishment below both dams. It also fails to meet both ecosystem and fisheries restoration goals, and thus is not a true comparison of benefits or costs.

CONCLUSION

Passage of the act has provided an excellent opportunity to resolve litigation associated with a contentious federal licensing proceeding and to restore the ecosystem of a major anadromous-salmonid-producing river. Dam removal, as well as ecosystem and fishery

restoration, are feasible. Short-term economic costs are high, but the long-term returns are substantial.

REFERENCES

- Bonneville Power Administration. 1992. Supplementation in the Columbia Basin. RASP Summary Report Series. Part I. Project No. 85-62. Division of Fish and Wildlife, Portland, OR.
- Brannon, E., and W. Hershberger. 1984. Elwha River fall chinook salmon. Pages 169-172 in J. M. Walton and D. B. Houston, ed. Proceedings of the Olympic Wild Fish Conference, Peninsula College, Port Angeles, WA.
- Brickell, D., and J. Goering. 1970. Chemical effects of salmon decomposition on aquatic ecosystems. Pages 125-138 in R. Murphy and D. Nyquist, ed. International Symposium on Water Pollution Control in Cold Climates. University of Alaska and Federal Water Quality Administration.
- Brown, B. 1982. Mountain in the Clouds: a Search for the Wild Salmon. Simon and Schuster, New York.
- Cederholm, C., D. Houston, D. Cole, and W. Scarlett. 1989. Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. Can. J. Fish. Aquat. Sci. 46:1347-1355.
- Donaldson, J. 1967. The phosphorous budget of Iliamna Lake, Alaska, as related to the cyclic abundance of sockeye salmon. Doctoral Thesis. University of Washington, Seattle.
- Durbin, A., S. Nixon, and C. Oviatt. 1979. Effects of the spawning migration of the alewife, *Alosa pseudoharengus*, on freshwater ecosystems. Ecol. 60: 8-17.
- Federal Energy Regulatory Commission. 1993. Proposed Elwha (FERC No. 2683) and Glines Canyon (FERC No. 588) Hydroelectric Projects, Washington. Volume 1. Office of Hydropower Licensing, Washington, DC.
- Federenko, A., and B. Shepherd. 1986. Review of salmon transplant procedures and suggested transplant guidelines. Can. Tech. Rep. Fish. Aquat. Sci. No. 1479.
- Hansen, A. 1987. Regulation of bald eagle reproductive rates in southeast Alaska. Ecology 68: 1387-1392.
- Heggens, J. and R. Borgstrom. 1988. Effect of mink, *Mustela vison* Schreber, predation on cohorts of juvenile Atlantic salmon, *Salmo salar* L., and brown trout, *S. trutta* L., in three small streams. J. Fish Biol. 33: 885-894.
- Hiss, J., and R. Wunderlich. 1994. Salmonid availability and migration in the middle Elwha River system. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.
- Hosey and Associates. 1988. Elwha Project (FERC No. 2863) and Glines Project (FERC No. 588). Response to Federal Energy Regulatory Commission request for additional

- information of May 28, 1987, dated May 27, 1988. Volume 2. Prepared for James River II, Inc., Port Angeles, WA.
- Kwain, W., and E. Thomas. 1984. The first evidence of spring spawning by chinook salmon in Lake Superior. *N. Am. J. Fish. Manage.* 4:227-228.
- Maib, C. Undated. A historical note on the Elwha River, its power development, and its industrial diversion. Stream Improvement Division, Washington Department of Fisheries, Olympia, WA.
- Mathisen, O. 1971. Escapement levels and productivity of the Nushagak sockeye salmon run from 1908 to 1966. *Fishery Bulletin* 69(4):747-763.
- Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* (Bethesda) 16(2):4-21.
- Newbold, J. 1987. Phosphorous spiralling in rivers and river-reservoir systems: implications of a model. Pages 303-327 in J. Craig and J. Kemper, ed. *Regulated Streams, Advances in Ecology*. Plenum Press, New York.
- Nickelson, T., M. Solazzi, and S. Johnson. 1986. Use of hatchery coho salmon (Oncorhynchus kisutch) psmolts to rebuild wild populations in Oregon coastal streams. *Can. J. Fish. Aquat. Sci.* 43:2443-2449.
- Reisenbichler, R. 1988. Relation between distance transferred from natal stream and recovery rate for hatchery coho salmon. *N. Amer. J. Fish. Manage.* 8:172-174.
- and S. Phelps. 1989. Genetic variation in steelhead (Salmo gairdneri) from the north coast of Washington. *Can. J. Fish. Aquat. Sci.* 46:66-73.
- Richey, J., M. Perkins, and C. Goldman. 1975. Effects of kokanee salmon (Oncorhynchus nerka) decomposition on the ecology of a sub-alpine stream. *J. Fish. Res. Board Can.* 32:817-820.
- Schoeneman, D., and C. Junge. 1954. Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River. *Research Bulletin No. 3*. Washington Department of Fisheries, Olympia, WA.
- Seiler, D. 1991. Coho production potential above Snoqualmie Falls. Open File Report dated January 15, 1991. Planning, Research, and Harvest Management Division. Washington Department of Fisheries, Olympia, WA.
- Spencer, C., B. McClelland, and J. Stanford. 1991. Shrimp stocking, salmon collapse, and eagle displacement. *Bioscience* 41: 14-21.
- Stalmaster, M., and J. Gessamen. 1984. Ecological energetics and foraging behavior of overwintering bald eagles. *Ecol. Monogr.* 54(4):407-428.
- Stone and Webster Environmental Services. 1991. Evaluation of the Eicher screen at Elwha Dam: 1991 test results. Research Project 2694-1. Research Reports Center, Electric Power Research Institute, Palo Alto, CA.